CS 520: Introduction to Artificial Intelligence

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Lecture 15: Planning Algorithms

Review: Planning

- **Specialized methods for a particular kind of task:**
  - **Representation and algorithms less general but more efficient**
  - **Note that even human brain appears to have specialized hardware for many tasks**
    - **Vision, speech, …**

Planning

- Given: start and goal states, and a set of operations
- Find: a sequence of operations that gets from start to goal
- What is special about this problem?
  - State is a set of assertions (facts, FOL sentences)
  - Operations change a subset of the assertions
  - Limited interaction between subproblems

The Strips Language for Planning

- states are represented as conjunctions of function-free ground literals, e.g.,

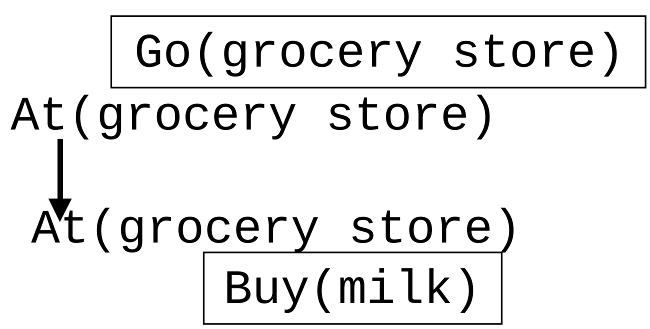
  At(Home) ^ ~ Have(Milk) ^ ~Have(Bananas) ^ …
  - states may be incomplete - positive literals not mentioned are assumed to be false.
- goals are conjunctions of literals, and can contain variables.
  - Literals not mentioned are assumed “don’t care”

Representing Actions in Strips

- **action description**
  - **Possibly parameterized, e.g. go(There)**
- **Precondition, e.g. at(Here)**
- **Effect**
  - **Add list, e.g. at(There)**
  - **Delete list, e.g. at(Here)**

Representing Plans

- **A plan is a graph whose nodes are actions**
  - **Also dummy actions for initial & final states**
- **Arc to each precondition showing which previous action makes that precondition true**



Representing Plans

- Also precedence arcs
  - This action must go before that action
  - Added to protect a precondition from being undone between time established and time needed.

Building Plans

- Progression
- Means-Ends
- Regression

Progression

Plan(S,G):

If (S satisfies G)

then Return(NI L)

else a. Let A be the set of operator instantiations applicable to S.

b. If A =   then Fail.

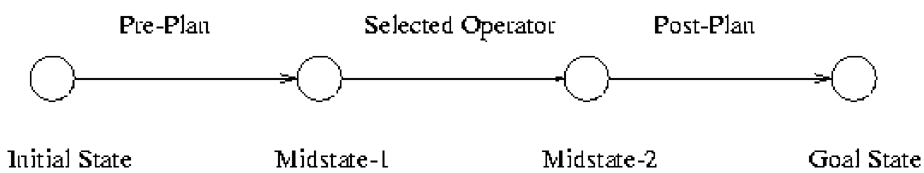
c. Let I = Choose from A.

d. Return(Cons(I,Plan(Apply(I,S),G))).

Evaluation of Progression

- **Not bad for small number of operators.**
- **Branching factor grows as we add operators.**
  - **E.g., Operators for painting blocks.**
  - **E.g., Operators for rotating blocks.**
- **Branching factor grows as we add objects.**
  - **E.g., More blocks.**
  - **E.g., More paint colors.**
- **Operators are chosen without regard to their relevance to achieving goals.**
- **Algorithm is complete.**

Means-Ends Planning



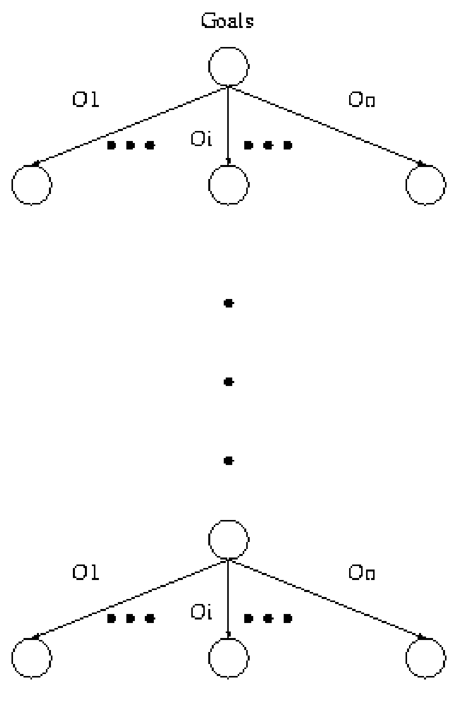
Means-Ends Planning

Plan(S,G):
If (S satisfies G)
then Return(NIL)
else a. Let A = Set of operator instantiations that add a literal L that is in G and is not sastified in S.
b. If A = {} then Fail.
c. Let I = Choose from A.
d. Let P = Plan(S,Preconditions(I)).
e. Let S = Apply(P,S).
f. Let S = Apply(I,S).
g. Let R = Plan(S,G).
h. Return(Append(P,Cons(I,R))).

Evaluation of Means-Ends Planning

- Operators are chosen with an eye towardtheir relevance to achieving goals.
- Algorithm is not complete.

Regression (Backward Chaining)



Regression (Goal stack planning)

Plan(S,G):

If (S satisfies G)

then Return(NIL).

else a. Let A = Set of operator instantiations that add a literal L in G, and that delete no literal in G.

b. If A = {} then Fail.

c. Let I = Choose from A.

d. Let G = Regress(G,I).

e. Let P = Plan(S,G).

f. Return(Append(P,List(I)).

Goal Regression

- **apply an action backwards to produce subgoal expressions.**
  - **unify one of the literals in the (sub)goal expression with one of the literals in the add list of the rule.**
  - **subgoal expression is created by regressing the other (nonmatched) literals in the goal expression through the instantiated rule,**
  - **and conjoining these with the preconditions of the instantiated rule.**

Examples

- **Goal: [ON(A,B) ^ ON(B,C)] , Action: stack(A,B)**
  - **ON(A, B) unifies with ON(X, Y) effect of stack, with A/X, B/y**
  - **Regress rest of goal , I.e, ON(B, C) through stack(A, B), giving ON(B, C).**
  - **Add preconditions HOLDING(A),CLEAR(B)**
  - **to yield the subgoal:**
  - **[ON(B,C) ^ HOLDING(A) ^ CLEAR(B)]**
- **Goal: CLEAR(A) , Action: unstack(x, A)**
  - **Unifies with CLEAR(y) effect of unstack(x, y)**
  - **Add preconditions to get subgoal [HANDEMPTY ^ CLEAR(x) ^ ON(x,A)].**

Examples

- **Goal: [CLEAR(A) ^ HANDEMPTY] , Action: unstack(x, A)**
  - **Unifies with CLEAR(y) effect of unstack(x, y)**
  - **But when we try to regress HANDEMPTY through clear(A) we fail, because HANDEMPTY is is delete list of clear.**

Regression on Sussman Anomaly

GOAL DESCRIPTION: ON(A,B)* ON(B,C)

INITIAL STATE: ON(C,A) ONTABLE(A)
ONTABLE(B) CLEAR(B)
CLEAR(C) HANDEMPTY

REGRESS STACK(A,B): HOLDING(A)* CLEAR(B)

....

ON(B,C)

REGRESS PICKUP(A): ONTABLE(A) CLEAR(A)
HANDEMPTY*

....

CLEAR(B)* ON(B,C)*

Regression on Sussman Anomaly: Cont'd

REGRESS STACK(B,C): HOLDING(B)* CLEAR(C)

....

ONTABLE(A) CLEAR(A)

REGRESS PICKUP(B): ONTABLE(B) CLEAR(B)

HANDEMPTY*

....

CLEAR(C)* ONTABLE(A)

CLEAR(A)

Regression on Sussman Anomaly: Cont'd

REGRESS PUTDOWN(C): HOLDING(C)*

....

ONTABLE(B) CLEAR(B)

ONTABLE(A) CLEAR(A)*

REGRESS UNSTACK(C,A): ON(C,A) CLEAR(C)

HANDEMPTY

....

ONTABLE(B) CLEAR(B)

ONTABLE(A)

Evaluation of Regression

- **Operators are chosen with an eye toward**
- **their relevance to achieving goals.**
- **Algorithm is complete.**

Abstraction

Problem -> Abstract Problem

--> Abstract Solution ->Concrete Solution

Example: hierarchical planning

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Causes of Plan Failure

- **bounded indeterminacy: actions can have unexpected results, but the possible effects can be enumerated and built into the action description axiom.**
- **unbounded indeterminacy: the set of possible outcomes is too large to enumerate. We must replan when our predictions are wrong.**